Mid-Semester Test

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Course No./Title : EEE F472/Satellite communications

DATE: Oct. 10^{th}, 2023. Test duration: 90 Mins. Max. marks: 30.

(*Note*: You may use standard results or formulae by stating them explicitly. Highlight your final answers in rectangular boxes. Simplify your response to the extent possible. Use notation consistently.)

Part-I: Answer the following. (10 points)

Note: Each question carries 1 point. Just write down the final simplified answer. There is no partial marking.

1. Consider an analog satellite communication link that uses wideband frequency modulation (FM). Express the modulation index (β_f) in terms of FM transmission bandwidth (B_T), RMS baseband frequency f_{rms}.

2. What are the segments of end-to-end satellite communication system? Write down the key segments.

3. Consider a digital satellite earth station transmitter. It uses the following signal for the Nyquist pulse shaping: $p(t) = \frac{\cos(\pi\beta R_s t)}{1-(2\beta R_s t)^2}\frac{\sin(\pi R_s t)}{\pi R_s t}$, where R_s denotes the symbol rate. When the roll-off factor $\beta \to 0$ is used, what is the maximum frequency component of $P(f)$ in terms of bit rate (R_b)? Assume $M-$ary phase shift keying (MPSK) modulation.

4. A digital satellite link achieves a symbol error rate of 10^{-9} under clear air conditions. Determine the approximate CNR (in dB) of the RF receiver. Assume binary phase shift keying (BPSK) modulation.

5. Provide a clear illustration depicting multilayers of satellite communication architecture considering different altitudes. In the illustration, show at least four layers by labeling them.

6. Consider a digital satellite communication system that uses minimum shift keying (MSK). In it, Δf denotes the minimum frequency spacing, allowing two orthogonal frequency shift keying (FSK) signals. Determine $\frac{1}{\Delta f}$ when the bit rate is 20 Mbps.

7. Consider a digital satellite link transmitter that uses $4-$bit PCM and uniform quantizer. Assuming polar signaling, determine the value of $Q(x_k)$ for $a_k = (+1, +1, +1, +1)$ and when the maximum signal amplitude $A_m = 5$ V. *Note:* $Q(x_k) = A_m \sum_{j=1}^{n} a_{kj} \left(\frac{1}{2}\right)^j$.

8. Describe the Walker constellation of VLEO satellites. What is the key motivation for building such satellite constellations?

9. Digital satellite transmitter uses analog to digital conversion (ADC) that involves sampling, quantization, and encoding. Write down the three stages that are combined to achieve the characteristics of a non-uniform quantizer?

10. Consider single-tone wideband FM. Suppose the maximum frequency deviation is 72 KHz and $f_{\max} = 8$ KHz. Further, the threshold CNR is 18 dB. The demodulated SNR (in dB) is approximately ————.

Part-II: Valid or Invalid (5 points)

Note: Write down Valid/Invalid. Justify in one or two sentences. No credit for incorrect justification.

1) Amplitude-companded single sideband (ACSSB) modulation was used in analog satellite communication. Implementation of ACSSB requires an expander in the transponder receiver.
2) Consider the implementation of the pulse code modulation in an earth station transmitter of a digital satellite communication link. In it, an analog voltage signal is sampled, and each sample is quantized into one of $\mathcal{L}$ levels. If the sampling rate is equal to the Nyquist rate (f_N), $\mathcal{L} = 2^{\frac{f_N}{R_b}}$, where R_b denotes bit rate.
3) Consider a $2-$bit PCM (with uniform quantization) used in a digital satellite earth station transmitter. In it, the signal power to quantization noise power ratio (SNR$_q$) is 13.76 dB. If the effective SNR is -20.01 dB, the approximate SNR due to the thermal noise (SNR$_n$) is -20 dB.
4) Consider an earth station antenna operating at 8.4 GHz. If the diameter of the circular aperture, which is the largest dimension of the antenna, is 5 m, the radiating near field boundary (i.e., Rayleigh distance) is approximately 2.8 km.
5) Suppose the received CNR at the earth station receiver is 10 dB. When the binary phase shift keying (BPSK) modulation is used, the exact theoretical symbol error probability (SEP) can be upper bounded as SEP $\leq e^{-10}$.

Part III: Answer the following questions. (15 points) [*Note:* Provide key intermediate steps.]

1. [Angle of elevation and Coverage area][5 points]

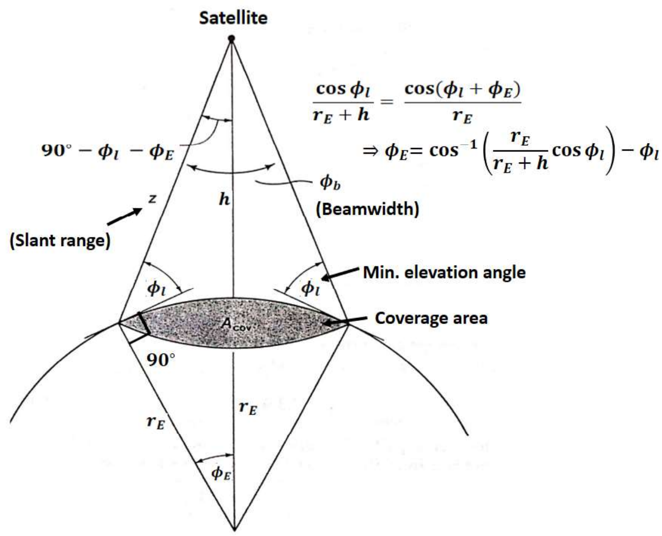

Fig. 1. Pertaining to Q.1.

Refer to the figure shown. Suppose the slant rage is equal to 41207 km. Assume $r_E = 6370$ km and orbit radius 42242 km. *Answer the following:*

i). Determine the minimum angle of elevation ϕ_ℓ (in degrees) and the angle ϕ_E (in degrees).

ii). Compute the coverage area (in km^2.)

iii). Compute the round-trip time (RTT) delay.

2. [On Deemphasis filter and modulation index] [5 points]

Consider the wideband FM-based analog satellite communication link for video transmission. The video is band-limited to $f_{\max} = 4.5$ MHz. Suppose the SNR improvement due to preemphasis and deemphasis is 18 dB. *Answer the following:*

i) Comment on the nature of the deemphasis filter.

ii). Determine the cutoff frequency and deemphasis filter transfer function. *Hint:* $11 < \frac{f_{\max}}{f_0} < 15$, where f_0 denotes the cutoff frequency.

iii). The rms frequency deviation $\Delta f_{\text{rms}} = \frac{18}{\sqrt{2}}$ MHz. Determine the modulation index.

3. [Equivalent noise temperature, Figure of merit] [5 points]

A satellite RF receiver has multiple stages. Consider the following approximation: $T_1 \approx T_2 \approx T_3 \ldots$ and $G_1 \approx G_2 \approx G_3 \ldots$. Let B_n denote the noise bandwidth. *Answer the following:*

i). Using the approximation, derive expressions for equivalent noise temperature (T_{eq}) and noise power. Simplify the expressions to the extent possible. *Note:* Recall that $(1-y)^{-1} = 1 + y + y^2 + \ldots$.

ii). Using the simplified expression for the T_{eq}, obtain an expression for the receiver figure of merit. Note that G_r denotes the receiving antenna gain.

iii). Suppose that the figure of merit is -3 dBK^{-1} and $G = 10$ dB. Assuming $T = 290$ K, determine the receive antenna gain.

□ **END OF QUESTION PAPER** □